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EVALUATION OF THE HIGH RATE WATER FILTRATION PROCESS

THE ONTARIO WATER RESOURCES COMMISSION

EVALUATION

OF THE

HIGH RATE WATER FILTRATION PROCESS

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NOTE

1. In all cases "gallons" refer to Imperial gallons unless otherwise specified.

2. Unless otherwise specified, the term "dual-media" is used to describe a filter in which approximately 6 inches of sand (effective grain size 0.4$\pm$mm) rests on a suitable gravel and underdrain system and supports approximately 24 inches of anthracite (effective grain size 1.0$\pm$mm).

SUMMARY

The proposed use of high rate water filtration processes is now wide spread in the Province of Ontario and the Ontario Water Resources Commission has therefore, undertaken a comprehensive evaluation of the process.

From a search of published material it is evident that the process, though in limited use for many years still presents problems in operation. From a theoretical evaluation it would appear that raw water quality is a critical factor in the process. A raw water of high turbidity (greater than 35 units) and/or containing significant amounts of algae will not be treated economically by the high rate filtration process. Other raw water qualities such as low temperatures, colour, taste, odours, and alkalinity may have adverse effects on the functioning of the filters.

Proponents of the high rate filtration process claim the elimination or reduction of sedimentation facilities as an advantage but it would appear that this may be done in only a few cases where unvaryingly good quality raw water is available.

All of the installations inspected had pretreatment facilities including sedimentation basins providing retention periods varying from 1-½ to 4 hours. There was no evidence to indicate that sedimentation facilities may be omitted unless the raw water quality is unvaryingly good, with turbidities of less than 20 Jackson units (JU) and with little or no algae.

With adequate pretreatment facilities to remove algae present in any significant numbers, and to reduce turbidities to less than 35 JU, dual-media filter units when operated at filtration rates of 5 to 10 U.S. gallons per minute per square foot of surface area will produce a finished water of excellent quality. Backwash water volumes will be approximately 2 percent of production.

Difficulties caused by unusual raw water conditions will be as severe in a high-rate filtration system as in a conventional system. There is no indication that additional problems will be experienced in a high-rate system assuming equal pretreatment facilities.

Improved control systems, including recording turbidity meters and pilot filters to supplement the standard jar testing procedures, are an advantage in any water treatment plant.

It is concluded that the use of dual-media filters rated at design flows of greater than 2 gpm/ft^2 surface area is feasible, but that such use should not preclude the installation of conventional facilities.

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1.0 INTRODUCTION

With the advent of growing interest in the treatment of municipal water supplies in the Province of Ontario by means of the High Rate Filtration Process the Ontario Water Resources Commission authorized the preparation of a report evaluating the process.

The report presented herewith is based on information obtained from published material, from theoretical evaluation of the process, and from data obtained by inspecting operating installations.

1.1 Conventional Rapid Sand Filtration

In the conventional rapid-sand filtration water treatment process, a clear effluent is produced by coagulating and settling as much of the material causing turbidity as possible, and filtering the settled effluent through a sand bed.

Alum or other inorganic coagulant is added to the raw water in sufficient quantity to cause not only coagulation of the particulate matter, but also agglomeration to the extent that the floc will settle readily if placed in a quiescent environment, (settling basins). Not all of the floc will settle but the major part of that which remains in suspension may be removed by passing the water through a sand filter. The sand filter consists of approximately two to three feet of sand of 0.5 millimetres $\pm$ effective grain size (d_{eff}) supported by a gravel layer on a system of underdrains. Only the top few inches of the filter removes particulate material and when a layer of filtered material forms on the filter surface the head loss becomes excessive and the bed is backwashed.

The standard rate of filtration is approximately two gallons per minute (gpm). Filter runs vary with the quality of water applied to the filter and this in turn is dependent upon the quality of raw water and effectiveness of the settling basins. A finished water of less than 0.1 Jackson Units (JU) of turbidity may be produced.

1.2 <u>High Rate Filtration</u>

The high rate filtration process differs from conventional rapid sand filtration in the construction of the filter beds, in the theory of removal of particulate matter, and in the rate at which water is applied to the filters.

For raw waters containing approximately 25 JU or less turbidity, published reports claim that settling basins may be omitted from the high rate process. (10) If the turbidity of the raw water exceeds this amount, settling basins are used in the same manner as in a conventional process except that the required efficiency is not as high. Assuming a raw water of low initial turbidity, the high rate process consists of the addition of alum or other inorganic coagulant to the raw water in sufficient amounts to cause coagulation of the particulate matter. Agglomeration into floc particles large enough to settle readily is not only not required but is not desirable. Coagulation is almost instantaneous when the material in suspension comes in contact with the chemical coagulant and therefore the formation of the small floc particles takes place in the flash mixing tanks. The water containing this fine floc is applied directly to the filter beds.

The filter beds differ from those used in the conventional process in that the grading varies from coarse to fine, from top to bottom. The beds may consist of approximately two to three feet of anthracite (0.8mm $\pm$ d_{eff}) on top of approximately 6 inches of sand (0.4$\pm$mm d_{eff}) which in turn is supported on a gravel layer and underdrains as in the conventional process. The grain sizes and specific gravities of the filter media are selected so that

the desired grading is maintained under backwashing. Multi-media filter beds, utilizing three or more layers of material may also be used. (7,5)

The finely divided floc applied to the beds does not remain on top of the bed as in the conventional process but penetrates the anthracite layer, becoming entrapped as it progresses through the filter. The finer particles will penetrate more deeply but all particles should theoretically be entrapped at some point in the anthracite or sand layers. To increase the capacity of the filter bed to retain material, a polyelectrolyte is added to the water prior to its application to the filter.

The capacity of high rate filter beds in terms of amount of material retained per unit increase in head loss is obviously greater than for a similar sized conventional bed as the entire depth of bed, rather than the top layer, is available for storage. However, a higher rate of flow (approximately 5 gpm as compared to 2 gpm for conventional filters) is used, and with the reduction or elimination of settling facilities the applied particulate matter load is greater than for a similar conventional process. Thus filter runs for high rate units may not be appreciably longer than for conventional types.

The quality of finished water which may be produced in a high rate filtration unit will be equal to that produced by the conventional process.

1.3 Proprietary High Rate Filtration Processes

There are several firms presently marketing high rate water filtration processes under registered trade marks, and with patents pending on several process features.

The firms offering this process include Permutit, Graver, the MicroFLOC Corporation and the Roberts Filter Manufacturing Company.

An integral feature of each of the proprietary processes is the use of continuous monitoring and recording of the plant influent and effluent turbidity. A change in effluent quality produces an alarm condition and chemical dosages are then adjusted by the operator. It is claimed that the time lag between coagulant adjustment and change in effluent is approximately five to ten minutes.

The MicroFLOC Corporation states that they "treat the precise composition of the media and its selection techniques as proprietary information", but it would appear that the significant feature of each of the proprietary processes is the use of a particular water quality monitoring device (e.g. MicroFLOC Coagulant Control Centre, Roberts Manhattan Quality Control Centre).

In the following discussion no attempt will be made to differentiate between any proprietary process and the high rate water filtration process in general.

2.0 DISCUSSION OF HIGH RATE PROCESS

2.1 Advantages of High Rate Filtration

The advantages of high rate filtration are most obvious in terms of gallons of water produced per unit area of treatment facilities.

In the case of a raw water of low turbidity and particulate matter content, the elimination of settling basins would provide an appreciable saving in capital costs and plant area. Even with a raw water of high turbidity, a reduced size of settling basin required would produce some saving.

The use of higher filter rates per unit filter area effects a further saving in capital costs as the filter beds will be smaller for a given quantity of finished water.

Using only enough chemical coagulant to produce a filterable (as compared to a settleable) floc may effect an additional saving in terms of coagulant costs in some cases.

The advantages of the high rate process would thus appear to be in capital and operating costs obtained by producing more water per filtration unit, possibly with less chemicals, than for a conventional process.

The quality of finished water obtainable by the two processes is not appreciably different.

2.2 Problems Associated with the High Rate Water Filtration Process

As stated in the previous section the apparent advantages of the high rate process are the reduced capital and operating costs obtained by producing a larger quantity of finished water per filtration unit with the addition of less chemical coagulants. It is pointed out, however, that while these savings may obtain, they are not universally realized for all types of water. It is emphasized that in order to be certain of effecting worthwhile advantages in the treatment of a particular raw water, a proper process design, preferably based on a pilot plant study must be used. Such a study may

indicate that the introduction of a high rate process is not warranted.

The problems visualized as occurring in the use of the high rate process may or may not be unique to the process, i.e. they may also occur in the use of a conventional rapid-sand filter process, but the processes have sufficient differences that an attempt will be made to present all such problems in this report.

2.2.1 Capital Works

In a conventional rapid sand filter water treatment plant the facilities provided will include flash mixing for chemical coagulants flocculation basins settling facilities and filtration units, plus ancillary equipment for treatment of any particular water quality encountered. The high rate process will include, in addition to such ancillary equipment, flash mixing and filtration units, with if design raw water quality warrants it, sedimentation facilities. It is felt that the reduction in treatment units by elimination or reduction of settling basins will reduce the flexibility of the plant and inhibit its capacity to produce an acceptable water quality in case of a change in raw water quality. Thus the possibility of a change in raw water quality with the attendant necessity of modified treatment requiring additional treatment units must be carefully balanced against immediate capital cost savings obtained by constructing a plant of reduced size.

2.2.2 Operation

The conventional rapid-sand filtration process has been in general use for a length of time sufficient to acquaint operators with the problems involved and these have been reduced to a reasonably predictable number. In addition the process, by its design, involving large flocculation and settling basins, and a filter which tends to deteriorate by loss-of-head build-up rather than break-through, tends towards stability of operation.

In contrast, the high rate process, which has

not had common application to small municipal plants, still has a number of variables which have not been fully determined. In addition the nature of the process is such that closer and more accurate control is required to prevent the production of a poor quality water. Once the finite capacity of the bed to retain coagulated turbidity is exceeded, the bed will no longer produce satisfactory water at its rated capacity until it is backwashed. (9)

For these reasons caution should be exercised in the introduction of the high rate process if there is any doubt as to the degree of supervision available in respect to either operator qualifications or time available. The necessity of providing extended supervision by a highly trained staff may introduce an operating cost which is prohibitive.

2.2.3 Chemical Costs

One of the claimed advantages of the high rate process is the reduction of the amount, and therefore the cost, of chemical coagulants necessary, as compared to a conventional rapid sand filter process. However it is noted that with some raw waters using rapid sand filters, it is not always necessary to use chemical coagulation, with adequate clarification being provided by filtration without, or with intermittent, chemical dosage. It is felt that in the treatment of such waters by the high rate process, a continuous chemical dosage would be required if the entire filter bed is to retain particulate matter. If only the lower, finer material is used to retain such particulate matter, the filters will act in the conventional manner, the flow rate or operating cycle must be reduced, and the plant capacity will be reduced from the design figure.

In addition to the inorganic coagulants used, the necessity of adding a polyelectrolyte may present an additional operating cost.

It is therefore concluded that while a saving

in operating expenditures may be realized this is not always the case.[9] Again it is felt that a study of the particular raw water quality, preferably by a pilot study is warranted.

2.2.4 Raw Water Quality

The production of a high quality finished water by the high rate filtration process would appear to be dependent upon the raw water quality to a much greater degree than in the conventional rapid sand filter process. An evaluation of the chemical and physical phases of the process indicates certain elements of raw water quality which would appear to be particularly troublesome. There is little doubt that any raw water condition which may be treated by the conventional method may be treated by the high rate process but the degree of control and cost of treatment by high rate methods may become prohibitive and prove uneconomical.

As with the conventional process certain raw water constituents will be best treated by ancillary equipment. These elements include hydrogen sulphide, hardness and other materials which do not lend themselves to coagulation. In this respect the high rate process is similar to a conventional process and no advantage will accrue from the use of the high rate process.

Additional factors which may adversely affect the operation of the high rate process, either in themselves or in concert with other elements are:

1. Temperature

2. Alkalinity

3. Colour

4. Taste and Odour

5. Algae

A comprehensive evaluation of the ramifications of these possible facets of raw water quality is presented in the following section.

2.3 Effects of Raw Water Quality

A claimed advantage of the high rate water filtration process is that particulate matter may be removed with minimum amounts of chemical coagulants and the water produced will still have a better clarity than distilled water. There are, however, several questions which remain unanswered at this time with regard to the performance of this process under conditions when chemical coagulation in the raw water supply becomes extremely difficult or when it is necessary to employ powdered activated carbon for taste and odour control.

2.3.1 Variation in Raw Water Quality

According to available literature the success of the high rate filtration process is dependent upon the production of a filterable, rather than settleable, floc, and therefore at times it is possible to use only the minimum dosages of chemical to accomplish coagulation. The rate of application of chemicals is determined by means of turbidity measurements on the clarified water and these data are obtained through a continuous monitoring device. There is some doubt as to how quickly the waterworks operator will be able to make the necessary proper adjustments to cope with any drastic change in the raw water quality due to wide fluctuations in turbidities and/or temperature.

2.3.2 Temperature Effects

Chemical and physico-chemical reactions proceed at much slower rates in water with low temperatures. Experience in conventional plants indicates that longer flocculation time and/or larger dosages of chemicals are required under these conditions. In some instances during the winter, if insufficient quantities of chemicals are used and if the coagulation reaction is incomplete there is a danger that some of the coagulants, particularly alum, may find a way into the distribution system and lead to problems of post-precipitation.

2.3.3 Alkalinity and Colour

In some water supplies in which the waters are very soft and low in alkalinity, and often are highly coloured, large dosages of chemicals are required to

promote floc formation. In many cases, weak floc particles are produced and they have a tendency to disintegrate very readily, resulting in poor settling and heavy loading on the filters. In spite of the design of high rate filters to accept a high particulate matter loading there is some doubt as to the capacity in a case such as this. It may further be necessary to determine the proper coagulant dosage by the use of jar tests. An excessive dosage of either inorganic or organic coagulant aid may result in blinding of the entire filter, and possibly binding of the filter media.

2.3.4 Activated Carbon

When a water supply becomes affected by severe taste and odour problems, one of the most practical methods of control is the application of powdered activated carbon. To obtain the maximum benefits, very finely powdered carbon should be considered and should be applied at a point in the waterworks plant where the optimum adsorption conditions will obtain. Ideally, carbon should be applied to the raw water at least ten to fifteen minutes ahead of other treatment chemicals to derive maximum benefits.

In conventional plants the carbon is applied at

a) the rapid mixing basin,
b) the flocculation tanks or
c) on top of the filters

The latter is not recommended as a point of application because of the short contact period and the possibility of breakthrough of fine carbon particles through the filters.

In the high rate process, unless sufficient coagulants are added to cause the agglomeration of the carbon particles and remove them completely in the coarse media of the filter, some breakthrough and some blinding in the lower fine sand portion of the filters may be expected. [10]

In order to derive maximum benefits from the

use of powdered carbon a pretreatment basin with a retention period of ten to fifteen minutes would be required ahead of the high rate filter units.

2.4 Effects of Algae

Water utilized by municipalities which is taken from a surface source of supply will invariably contain several to many species of algae which may be largely removed by sand filtration. In most municipalities where sand filtration is practised, coagulation and sedimentation are employed to prevent rapid clogging of the filters by algae and other particulate matter and so to lengthen the duration of the filter runs. In a few areas of the province, specialized measures must be implemented to render water treatment practical because of chronically high algae populations. At Belleville, standard water treatment practices would be impossible without the aid of microstrainers, which remove 80-85% of the algae present. In November of 1962, high levels of the diatom *Melosira* developed in Lake Ontario which affected the efficiency of filtration at nearly all water treatment plants between Kingston and Hamilton. The situation became so bad at the Scarborough Water Treatment Plant that it had to be temporarily removed from service.

Sand filters do not remove all of the algae from water passing through the filters. During investigations at Belleville in 1964, it was established that one-fifth of all of the small green algae, *Chlorococcum*, was passing through the filters. Occasionally, other larger types of algae were observed in the filtered water as well. These observations are in agreement with observations made at several cities in the United States. Experimental work undertaken by Borchardt and O'Melia [1] demonstrated that removal of algae by filtration decreases rapidly with time to a constant minimum value, and that significant numbers of algae were found in every effluent sample. They contend that for algae (nonflocculent particles) some surface straining takes place,

followed by continuous uniform removal at a low rate and that percentages of particles reaching the lower levels of the bed are substantial.

The major concern with respect to high rate filtration where high levels of algae are present would appear to be the possible penetration of algae through the anthrafilt and resulting accumulation on the surface of the sand and throughout the sand layer. It is recognized that poor floc formation may result when algae numbers are relatively high. At such times turbidity may be low because of the absence of larger particulate matter. It is a common waterworks practice to add clay to the raw water during periods of low turbidity to produce an artificial turbidity in order to obtain satisfactory removal of algae by inducing good floc formation. Thus, under clear water conditions, the potential impact of high algae populations on the sand layer where high rate filtration is in effect, can be visualized.

From data accumulated on algae condtions in Lake Erie, Lake Ontario, the Detroit River, the Bay of Quinte, the Trent River System, the Grand River and a few smaller inland lakes such as Ramsey Lake at Sudbury, it would appear that algae populations reach sufficiently high levels to necessitate comprehensive experimental studies before any high rate filtration system be adopted for water treatment plants utilizing these sources of supply.

3.0 Plant Operating Data

The following section consists of data compiled through inspection of water treatment plants using the high rate filtration process.

3.1 CITY OF JACQUES CARTIER, QUEBEC

MUNICIPAL WATER TREATMENT PLANT

3.1.1 General

Jacques Cartier is a municipality on the south shore of the St. Lawrence River, adjacent to the City of Montreal. The municipal water treatment facilities provide the entire water supply for the approximately 45,000 persons and 49 industries in Jacques Cartier, plus approximately 6 mgd which is sold to neighbouring municipalities.

The plant was initially constructed as a conventional rapid-sand filtration installation with a capacity of 12 mgd and in 1964 was expanded, by the addition of 6 filter units, to a capacity of 18 mgd. At the time of expansion one filter was constructed as a high-rate unit and comparative tests were run with this unit and using a conventional rapid-sand unit as a control.

3.1.2 Process

Water Source and Intake

Raw water is obtained from the St.Lawrence River between the St.Lawrence Seaway and Ile Ronde, at the eastern end of St. Helen's Island. Flow is by gravity through a 60 in. diameter intake to the raw water pumping station. From this station, with pumping capacity of 34 mdg (US), the water is pumped 8,000 feet to the filtration plant.

Chemical Addition and Mixing

The raw water is pre-chlorinated at a dosage of 0.7 ppm. Aluminum sulphate (alum) is added through mechanical injectors into flash mixers in dosages varying with raw water quality, as determined by a

"Zeta-meter". Determination of zeta potential, which is the measure of electro-kinetic charges around the particles of material suspended in liquid which create repulsion forces, and the reduction of such forces by chemical additives, (alum), is the basis of control in the Jacques Cartier plant.

Tests performed by plant staff indicated an optimum alum dosage of 3.5 grains per gallon to produce a zeta potential of zero. It is reported that this dosage produced maximum flocculation and precipitation.

Flocculation and Settling

After addition of alum and flash mixing the water is detained for 20 to 30 minutes in flocculating basins utilizing horizontal rotating paddle agitators. Settling basins, providing 3 to 4 hours retention, depending on flow, are used for removal of most of the particulate matter. Because the combination of settling and filtration is considered an integral part of the process, no record is kept of water quality as it leaves the sedimentation basin. Infrequent testing indicates that very low turbidities (1 to 5 JU) are applied to the filters.

Filtration

The Jacques Cartier plant was unique among those inspected in that it had both a high-rate and a conventional rapid-sand unit for comparison.

The conventional filter unit (Filter No.17) consisted of a 12-inch gravel layer overlaying a Wheeler underdrain system, and 30 inches of sand with an effective grain size of 0.38 to 0.45 mm.

The high-rate filter (Filter No.18) consisted of a similar underdrain system and gravel layer. On top of the gravel was a 6-inch sand layer (effective grain size 0.38 to 0.45 mm) and then a 24-inch layer of anthracite, with grain sizes ranging from 0.5 to 0.9 mm.

Each filter had a surface area of 394 square feet.

Backwash piping provided a controlled flow of 12 to 16 gpm/ft^2 filtering surface. Inlet and outlet piping was designed to accommodate the expected higher flows on Filter No.18.

On Filter No.18 a mechanical injector for polyelectrolyte feed was installed.

Recording turbidity meters, equipped with alarm signals, were installed on the raw water intake, and on the effluent piping of each filter.

For the purposes of testing the filter units the same quality water (from the sedimentation basins) was applied to each filter. Loss of head, filtration rate and effluent turbidities were recorded for each unit.

Results are shown in Figure 2.

Filter No.17 (conventional rapid-sand unit) was operated at 2 gpm/ft^2 and at 3 gpm/ft^2 flow rates. At these rates the filter was operated for 33 hours and 26 hours respectively, before indicating a six foot loss of head.

Filter No.18 (high-rate unit) was operated at flow rates of 2, 4, and 6 gpm/ft^2. At these rates the filter was operated for 150 hours, 60 hours, and 33 hours respectively before indicating a six foot loss of head.

Effluent quality was similar in all cases.

From these tests it is concluded that the high-rate unit can produce 4.5 times as much water as a conventional rapid-sand unit before backwashing when both units are operated at a rate of 2 gpm/ft^2. A high-rate unit operated at 6 gpm/ft^2 will produce three times as much water as a conventional unit operated at 2 gpm/ft^2, with equivalent loss of head.

Backwash

For each filter unit backwash water was applied at a rate of approximately 15 gpm/ft^2. This is considered the maximum rate to insure that the underdrain system is not disturbed.

At this backwash rate, Filter No. 17 (conventional) when operated for 33 hours at a filtration rate of 2 gpm/ft^2 required 35,000 gallons of wash water. This is equivalent to 2.25% of production.

Filter No.18 (high-rate) when operated for 150 hours at a filtration rate of 2 gpm/ft^2 required 45,000 gallons of wash water which is the equivalent of 0.6% of production.

After operating for 60 hours at a rate of 4 gpm/ft^2, 62,000 gallons (1.1%) of wash water were required for the high-rate filter.

Polyelectrolyte Filter Aid

An organic filter-aid was used in the high-rate filter only, being applied to the influent just prior to the filter bed. Application was normally at a rate of 5 ppb. During periods of low temperature (less than 45°F) in the filter influent, there was difficulty in dissolving the alum and higher dosages of polyelectrolyte were required.

3.1.3 Water Quality

Raw Water

a)	Bacterial	- coliform	1600/100 ml
b)	Chemical	- hardness	145 ppm
		- alkalinity	91 ppm
		- iron	0.18 ppm
		- chlorides	52 ppm
		- pH	8.2
c)	Biological	- algae	some
d)	Turbidity		9-90 ppm (600 max.)

Finished Water

a)	Bacterial	- coliform	0
b)	Chemical	- hardness	145 ppm
		- alkalinity	7.4 ppm
		- iron	0.1 ppm
		- chlorides	-
		- pH	7.0
c)	Biological	- algae	-
d)	Turbidity		0.08 ppm

3.1.4 Operation

The plant is supervised and in operation 24 hours per day. The staff consists of 24 men including the director and assistant director, chief operator, four shift foremen, four operators, four assistant operators, one laboratory technician and a maintenance staff. The plant is normally operated by a shift foreman, one operator and one assistant operator. The laboratory technician is on duty during the day.

3.1.5 Economics

No direct cost comparison figures are available for the high-rate filter but as shown above the production per unit area is higher than for a conventional unit and the cost per gallon of water produced is therefore assumed to be lower. The additional cost of larger piping is more than offset by the saving in filter area required.

3.1.6 Summary

The water treatment plant in the City of Jacques Cartier, Quebec, has 17 rapid-sand filters and one high-rate filter with the same surface area as each of the conventional units. Water is applied to the filters after the addition of alum, 30 minutes flocculation and approximately 3 hours sedimentation. Alum dosages are determined by zeta potential measurements and adjustment of the charge to zero. An organic polyelectrolyte is used on the high-rate filter only.

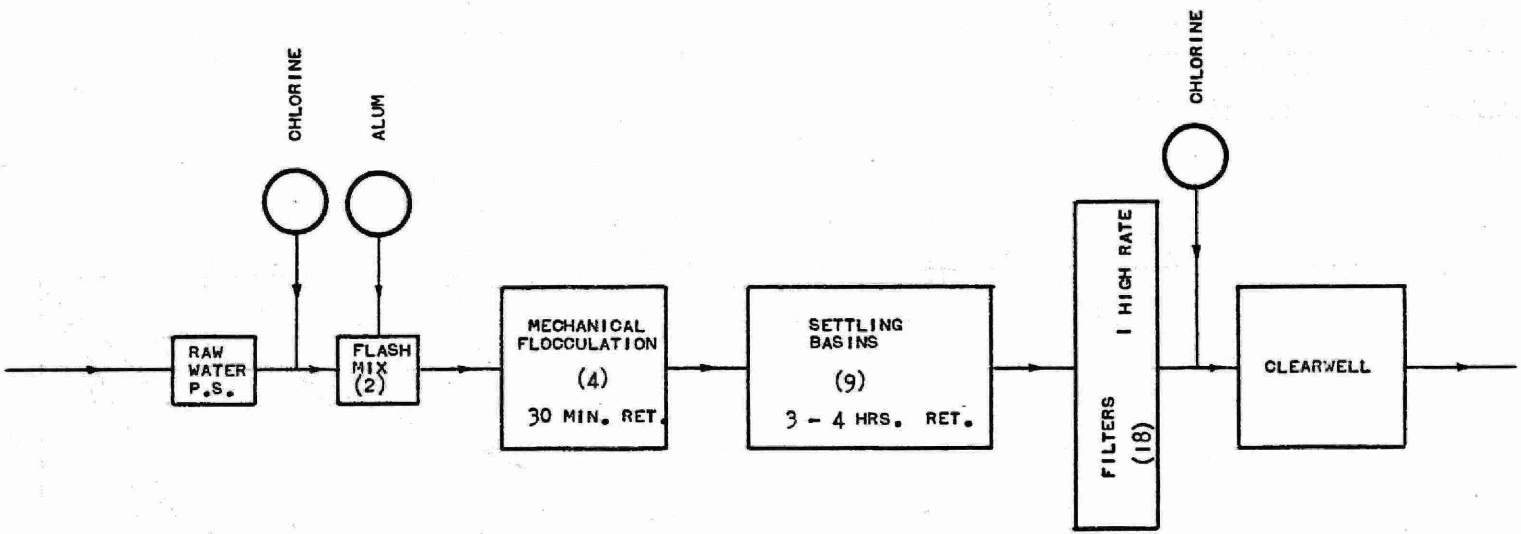
The conventional rapid-sand filters are operated at a rate of 2 gpm/ft^2 surface area. The high-rate unit has been operated for test purposes at rates of 2, 4 and 6 gpm/ft^2 surface area.

At a rate of 2 gpm/ft^2 the high-rate filter will operate for 150 hours with a terminal head loss of six feet, compared to 33 hours for the conventional unit. At a rate of 6 gpm/ft^2 the high-rate unit will operate for 33 hours with a terminal head loss of six feet.

Applying the same quality water to a high-rate unit and a conventional unit indicates that the high-rate unit may be operated for a period approximately three times as long as a conventional unit at the same flow rate, or at a rate three times as high for the same period. By operating at a high rate a considerable saving in required filter area is achieved.

The finished water quality as produced by a high rate unit is equal to, or better than, that produced by a conventional unit.

A higher degree of control is required than is normally found in a conventional treatment plant.



DESIGN CAPACITY - 18 MGD

AVERAGE FLOW - 12 MGD

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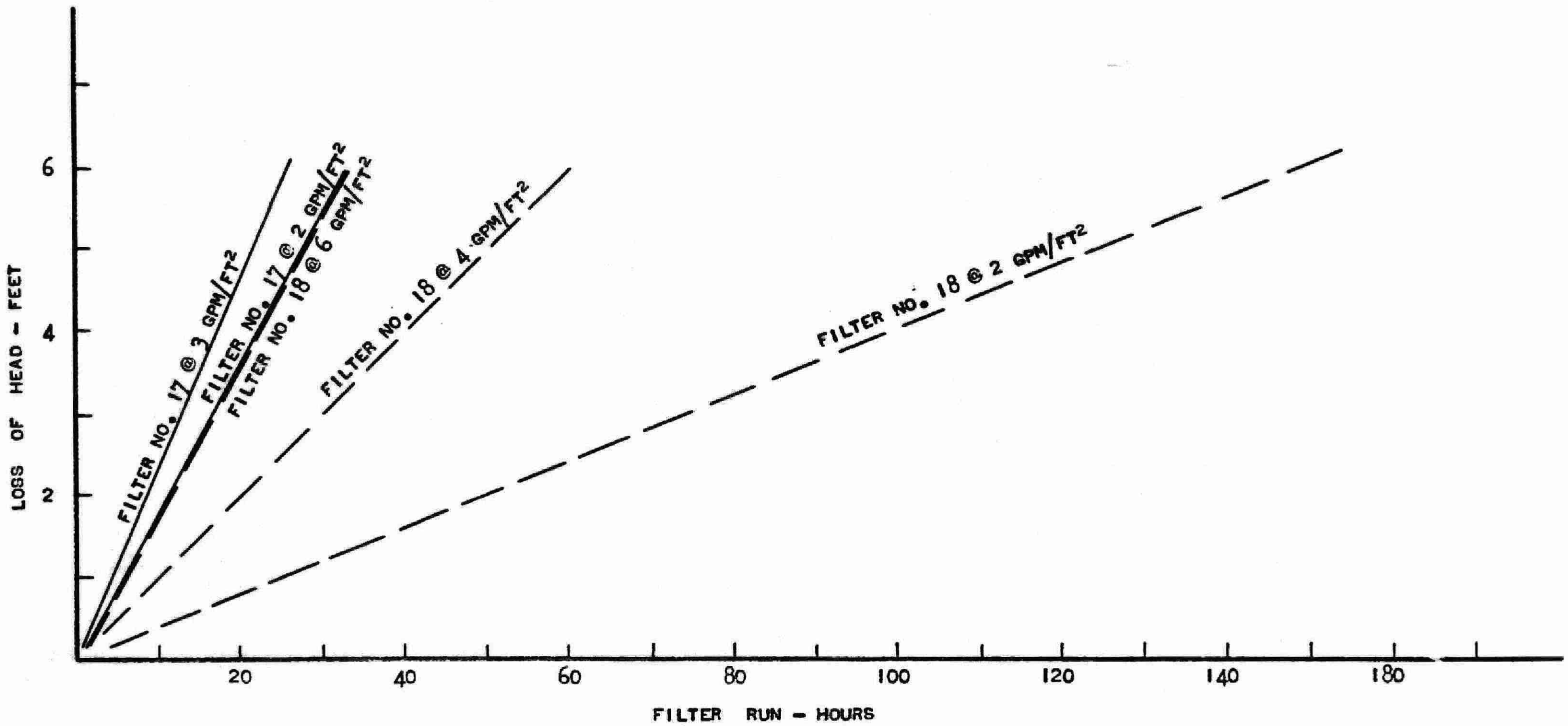
WATER TREATMENT PLANT

SCHEMATIC FLOW DIAGRAM

FIGURE 1



FILTER NO. 17 - RAPID SAND

FILTER NO. 18 - HIGH RATE

ONTARIO WATER RESOURCES COMMISSION
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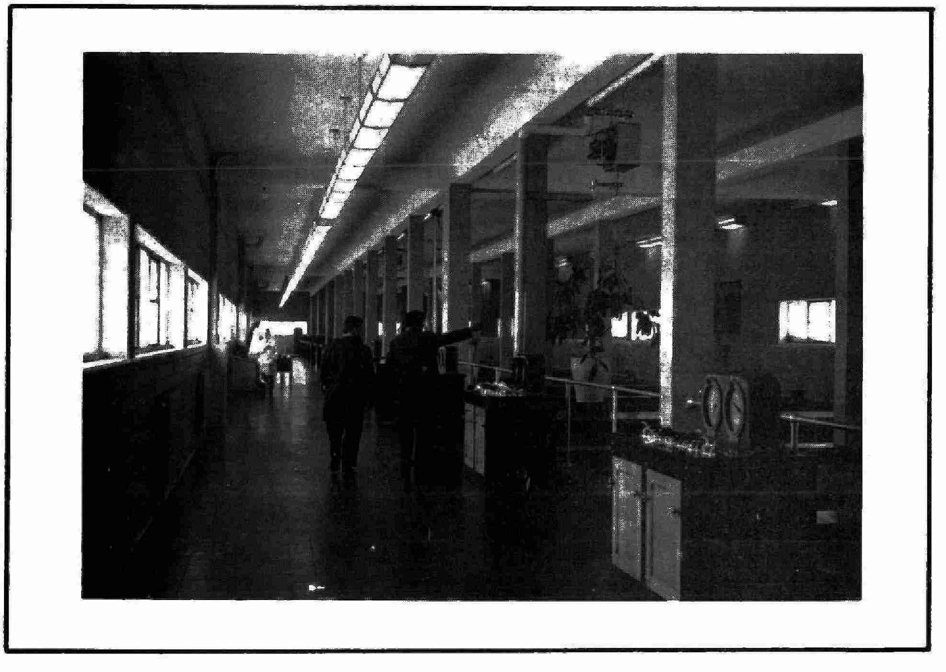
CITY OF JACQUES CARTIER

COMPARISON OF

HIGH RATE & RAPID SAND FILTERS

FIGURE 2

Sedimentation Basins



Filter Gallery

3.2 EUGENE, OREGON

HAYDEN BRIDGE FILTRATION PLANT

3.2.1 General

The municipal water system, including the Hayden Bridge Filtration Plant, is operated and managed by the Eugene Water and Electric Board, an elective five-member Board separate from other municipal governmental functions. Water is distributed to more than 80,000 people in the Eugene metropolitan area, including approximately 20,000 persons outside the city limits.

The Hayden Bridge Filtration Plant was originally constructed with conventional rapid-sand filters which have now been converted to high-rate units. The last three filters were converted in 1964, to give a total design filter capacity of 80 mgd (US). Pumping facilities limit the plant output to 60 mgd (US).

3.2.2 Process

Water Source and Intake

Raw water is obtained from the McKenzie River at Hayden Bridge. A pumping station at the river's edge supplies raw water through twin intakes 2,000 feet to the filtration plant which is situated on top of Vitus Butte, a height of land overlooking the area served.

Chemical Addition and Mixing

The raw water is pre-chlorinated and lime and alum are added. The chemicals are injected immediately upstream of a Parshall flume. The turbulence induced downstream of the flume, and flow through 180 feet of distribution channel is the only provision for mixing and flocculation. Chemical dosages are dependent upon raw water quality, with alum dosages varying from 4 to 75 ppm.

Flocculation and Settling

Flocculation facilities are limited to the 180 feet of distribution channel mentioned above. This provides approximately 30 minutes retention at average flows. Two sedimentation basins with a total volume of approximately 2 million gallons (US) provide a retention period of 50 minutes at a design flow rate of 60 mgd (US). To date (March 1966) the maximum 24 hour flow through the plant was 38.2 million gallons (US). Thus the actual minimum retention period in the sedimentation basins has been 75 minutes. At average flows (approximately 15 mgd (US)) the retention period in the sedimentation basins is 3 to 3½ hours.

It is reported by plant staff that raw water turbidities of 20 JU or less are not normally reduced by sedimentation but rather carry through to the filters. As raw water turbidities become higher the sedimentation facilities become more effective so that turbidities in excess of 50 JU are not applied to the filters.

Filtration

The Hayden Bridge filters were originally constructed as conventional rapid-sand units consisting of Wheeler under-drains, gravel support layer and 24 inches of quartz sand with an effective size of 0.4 mm. The conversion to high-rate filtration was accomplished by removing the top 16 inches of sand and replacing it with anthracite with an effective grain size of 1.25 mm. The hydraulics and piping originally installed were such that minimal modification was required.

The filters are designed to operate at a flow rate of 7 gpm(US)/ft^2. At this rate, and with an applied turbidity of approximately 15 JU, filter runs of approximately 24 hours are obtained, with a

head loss of 10 feet. A maximum effluent turbidity of 0.25 JU causes an alarm condition which also indicates the necessity of backwashing. A recording turbidity meter is installed in such a manner that the effluent from any one of the filters may be monitored. Normal practice is to monitor the turbidity on the filter which has been in service for the longest period.

Backwash

Backwashing of the filters is done as required either by loss-of-head (10 feet maximum) or by turbidity breakthrough. Normally loss-of-head is the controlling factor.

Backwash water is applied at the rate of 15 gpm(US)/ft^2 in conjunction with Palmer Filter Sweeps. Hydraulics of the backwash system are such that only half of a filter may be washed at a time at the 15 gpm/ft^2 rate. The volume of backwash water under average conditions is 150,000 gallons (US) or on the basis of a 24 hour run, at 7 gpm/ft^2 filtration rate, 2.5% of production.

Coagulant Aid

A polyelectrolyte coagulant aid is added to the water prior to filtration at water temperatures below $60^{o}F$. Dosages are variable but are approximately 5 ppb.

Control

A pilot filter is used as an aid in control of the process. A continuous sample is drawn off prior to the sedimentation basins and applied to a model filter. The turbidity of the model effluent is monitored, recorded, and transmitted to the laboratory. An excess of polyelectrolyte is added to the pilot filter to prevent breakthrough. Thus if turbidity is present above

the control limit in the effluent, it is assumed to be due to improper alum dosage. If the required alum adjustment is not obvious, jar tests are performed to determine the optimum dosage. The time from sampling to effluent for the pilot filter is approximately 15 minutes. Therefore the improperly coagulated water, as indicated by the pilot filter results, has not yet reached the filters and has been mixed with better quality water in the sedimentation basins. A coagulant dosage correction made quickly will correct the condition before any poorly coagulated water is applied to the filters or has reached the clear well. This factor of "lead-time" is considered the main advantage of the pilot filter.

3.2.3 Water Quality

Raw Water

a)	Bacterial	- coliform	av. MPN 250
b)	Chemical	- hardness	18 - 24 ppm
		- alkalinity	18 - 34 ppm
		- iron	0.05 ppm
		- chlorides	4.0 ppm
		- pH	7.1 - 8.0
c)	Biological	- algae	moderate
d)	Turbidity		2.0 - 2250 JU
			av. 17 JU

Finished Water

a)	Bacterial	- coliform	0
b)	Chemical	- hardness	15 - 34 ppm
		- alkalinity	18 - 32 ppm
		- iron	0.05 ppm
		- chlorides	8.0 ppm
		- pH	7.5
c)	Biological	- algae	none
d)	Turbidity		0.08 - 0.15 JU

3.2.4 Operation

The Hayden Bridge plant is staffed by seven operators all of whom are graduates of secondary school, or equivalent, and have attended a course in bacteriology. A plant superintendent is on duty 8 hours per day.

The operators report that the plant is not difficult to operate. Seasonal variations in raw water quality require process changes but after these changes have been made the operation again becomes routine.

The quality of water produced by the high-rate filters is equal to, or better than, that produced by a conventional rapid-sand filter.

3.2.5 Economics

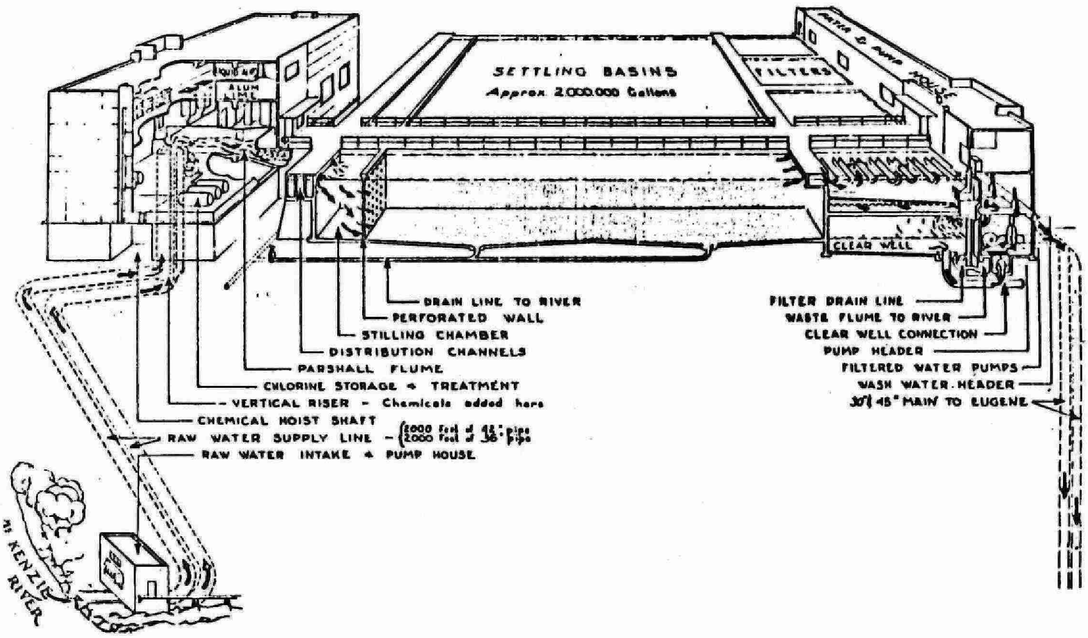
The cost of converting three of the filters from conventional to high-rate media, which in this case involved only the replacement of some of the sand with anthracite, is reported as $8,638 (US). Total cost of the plant, excluding land, legal and engineering fees was $2.75 million. The average cost of water production is reported as $60 per million gallons (US).

3.2.6 Summary

The Hayden Bridge Filtration Plant which serves the metropolitan area of Eugene, Oregon was originally constructed as a conventional rapid-sand filtration installation and was converted to a high-rate filtration plant by introducing a dual-media filter cross-section. This allowed higher unit area flows through the filters,thereby providing increased capacity without structural expansion. The hydraulic capacity of the original plant was such that very little modification was required. Sedimentation basins, giving retention times of 3 to 3-1/2 hours at average flows, are provided.

The raw water is normally of good quality,

having low (17 JU) turbidity and very low algae populations. The finished water is of good quality, having a turbidity of less than 1 JU.



SCHEMATIC DRAWING OF

HAYDEN BRIDGE FILTRATION PLANT

CITY OF EUGENE, OREGON

FIGURE 3

3.3 GRANTS PASS, OREGON

MUNICIPAL WATER TREATMENT PLANT

3.3.1 General

The municipal water treatment plant in the City of Grants Pass in southern Oregon was renovated in 1962, and at that time the five filter units were converted from conventional rapid-sands bed to high-rate beds. A minimum amount of piping modification was required to increase the design capacity of the filtration units from 4.5 mgd(US) to 10.5 mgd (US).

3.3.2 Process

Water Source and Intake

Raw water is obtained from the Rogue River upstream of the City of Grants Pass. There are four communities upstream of the intake with a combined population of approximately 43,000 persons. All of the wastes from these communities is discharged into the Rogue River after secondary treatment. The river is also subject to flash floods approximately 15 days per year.

The raw water is pumped from the river to the plant mixing basins.

Chemical Addition and Mixing

Chemicals are added to the raw water at the intake to the mixing basins. Lime is added for pH control, liquid alum is used as a coagulant and powdered activated carbon is used as required for taste and odour control. The raw water is also prechlorinated.

The dosage rate for alum may be determined by jar testing or by use of a pilot filter. The operator does not normally use the pilot filter as a control device as he feels that while it indicates the filterability of the coagulated water, it does not indicate the required alum dosage to produce good

filterability. The alum dosage varies from a low of 0.4 ppm in the summer to a maximum of 86 ppm in the winter.

Chemicals are injected into the influent stream and mixing is continued for approximately 30 to 45 minutes in a combined mixing and flocculating basin.

Flocculation and Settling

After the addition of alum, and other chemicals, mixing and flocculation is continued for a period of approximately 30 minutes in a slow mixing chamber. The operator feels that this is not an ideal arrangement and would prefer to have horizontal, rotating-paddle type flocculators. The two settling basins, with a total volume of 900,000 gallons (US) provide a retention period of approximately 2 hours at a flow of 10.5 mgd(US).

Reduction of turbidity through the sedimentation basins is reported as approximately 80% on the basis of an average raw water turbidity of 180 JU. Thus, under average conditions, the water applied to the filters has a turbidity of 35 JU or less.

Filtration

The plant is equipped with five filter units with a total surface area of 1,600 square feet. These filters were originally conventional rapid-sand beds but were converted to dual-media high rate filters at the time the plant was modernized. The filter beds now consist of cast iron pipe underdrain system, a graded gravel layer 21½ inches deep, a 6-inch sand layer (effective grain size 0.4 mm) and an 18 inch anthracite layer (effective grain size 1.0 mm, maximum grain size 4.5 mm).

The design filter flow rate is 7 gpm(US)/ft^2 but in practice flow rates vary from 2½ to 10 gpm(US)/ft^2 and are adjusted depending upon the water quality. During warm weather, and with low turbidities, higher flow rates are used. Filter runs vary from 1 hour to 30 hours, again dependent upon water quality. With a turbidity of 35 JU applied to the filters and a flow rate of 7 gpm(US)/ft^2, a filter run of approximately 2 hours is obtained.

With low water temperatures problems occur in both the sedimentation and filtration units. Dissolving alum becomes difficult at these temperatures, the floc is fragile and, probably because of a higher viscosity of the water, filter breakthrough occurs at a head loss of four feet. The addition of a polyelectrolyte will assist in controlling breakthrough but the dosage is critical in that an excess of polyelectrolyte will cause a bridging on the top of the sand layer with a resulting sludge deck and excessive head loss within the filter. Control of the process is delicate and critical.

During the year there are periods of moderage algae growth and when applied to the filter the algae are removed but cause a rapid build-up of head loss In this respect the algae act as any other particulate material. Activated carbon is applied to control taste and odour caused by algae, and also by traces of glue waste occasionally occurring in the raw water. The carbon is applied ahead of the settling basins. No problem of carbon breakthrough on the filters is reported.

Backwash

The filters are backwashed when required by excessive head loss or breakthrough. Wash water volumes per filter vary from 20,000 to 48,000 gallons. The average backwash usage is approximately 1.5% of production. This figure also varies with raw water quality.

3.3.3 Water Quality

Raw Water

a)	Bacterial	- coliform	max.11,000/5 ml
b)	Chemical	- hardness	58 ppm
		- alkalinity	60 - 90 ppm
		- iron	0.03 - 0.09 ppm
c)	Biological	- algae	moderate
d)	Turbidity	- The raw water turbidities are variable and show marked seasonal fluctuations. Turbidities of 1,800 to 1,900 units are experienced for periods of several days at a time and turbidities in the 2,600 unit range are obtained for periods of one day at a time. For four months, in the dry season, the turbidity averages between 10 and 18 units. For the remaining eight months the average turbidity is 180 units. Most of the turbidity is caused by glacial pumice.	
c)	Trade Wastes	- An upstream plywood mill occasionally discharges traces of glue wastes which cause a taste and odour problem in the water plant.	

Finished Water

a)	Bacterial	- coliform	none
b)	Chemical	- hardness	50 ppm
		- alkalinity	52 ppm
		- iron	0.01 - 0.03 ppm
		- pH	7.1

Finished Water - (Continued)

c) Biological - algae

d) Turbidity - 0.05 - 5 JU
avg. 0.07

3.3.4 Operation

The plant is supervised for 8 hours per day by a chief operator and operator. Both men are certified by the Oregon State Board of Health.

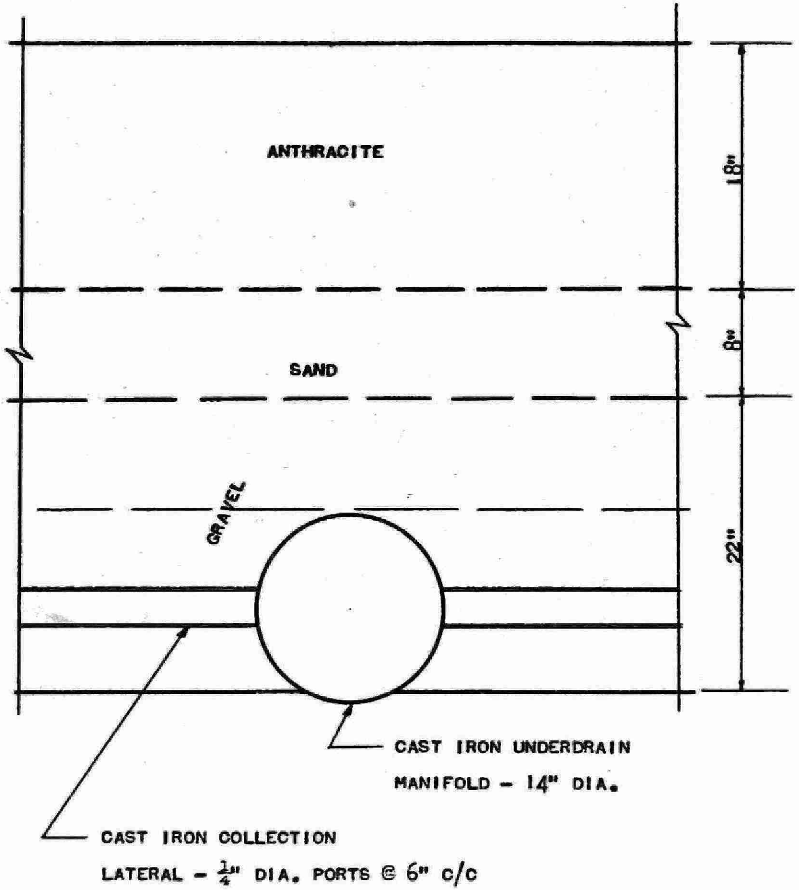
3.3.5 Summary

The plant, although converted to high rate filtration in 1962, is basically old and therefore subject to operating and maintenance problems generally associated with old installations.

The extreme variations in raw water quality cause difficulties in control of the process.

The quality of finished water is generally good and does not appear to be adversely affected by the use of filter rates in excess of the conventional 2 gpm/ft^2 flow rate, provided adequate pretreatment is provided. Turbidities in excess of 35 JU applied to the filters, particularly in cold weather are not practical.

Because of the age of the basic treatment units and the necessary compromises made in converting to high-rate filtration, the operating characteristics of this installation can not be considered typical of the process as such although they do typify the problems which may be encountered in attempting such a conversion.



U.S. SIEVE	% PASSING ANTHRACITE	% PASSING SAND
4	99-100	
6	95-100	
14	60-100	
16	30-100	
18	0-50	
20	0-5	96-100
30		70-80
40		10-20
50		0-10
70		0-2

FILTER MEDIA SIEVE ANALYSIS

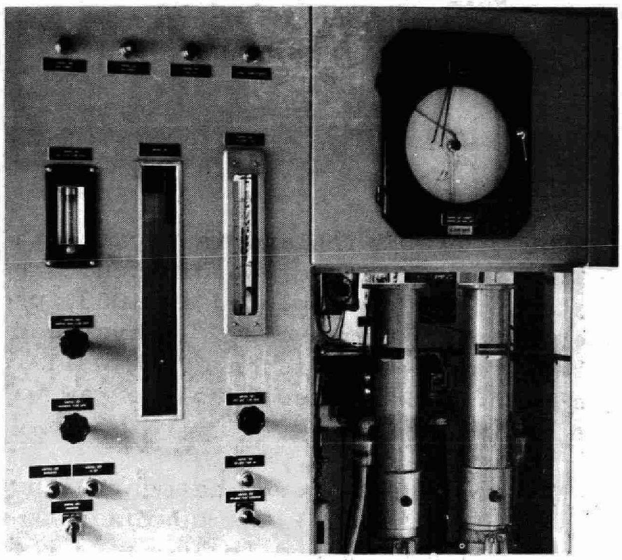
ONTARIO WATER RESOURCES COMMISSION
DIVISION OF RESEARCH

GRANTS PASS, OREGON

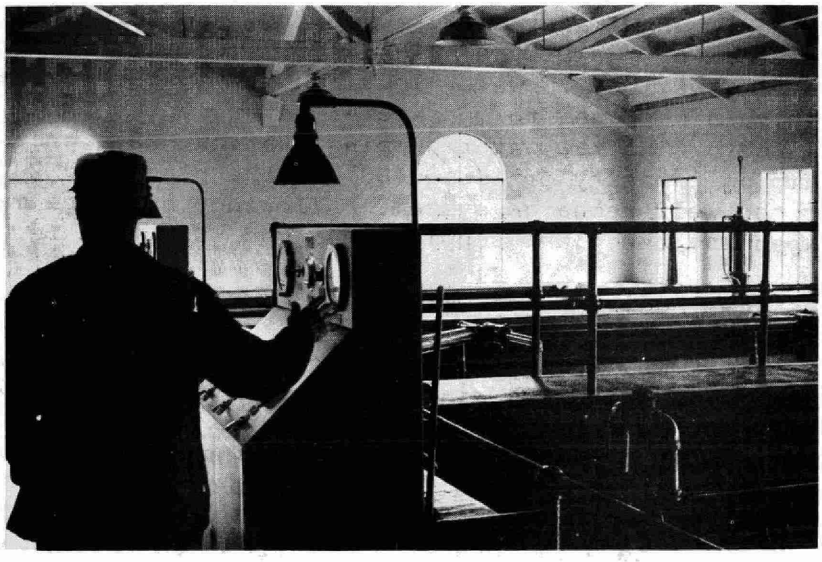
MUNICIPAL WATER TREATMENT PLANT
TYPICAL FILTER SECTION

FIGURE 4

Municipal Water Treatment Plant



Pilot Filter and Turbidimeters



Filter Gallery

3.4 CITY OF RICHLAND, WASHINGTON

COLUMBIA WATER TREATMENT PLANT

3.4.1 General

The City of Richland is located in the south-central part of the State of Washington. The Columbia Water Treatment Plant, completed in 1963, provides the basic water supply for the city. A system of wells is also in use but the water is hard. A well recharge system has been incorporated into the raw water pumping station at the plant.

The Columbia Water Treatment Plant, with a present capacity of 15 mgd(US) was designed to use high-rate filters. It is planned to increase the plant capacity to 45 mgd (US) in the future and all piping, valves, etc. have been designed for this amount.

3.4.2 Process

Water Source and Intake

Raw water is obtained from the Columbia River upstream of the City of Richland. The river is subject to fluctuations in water level and the water intake has been designed to operate at water depths from 9 to 31 feet. The raw water pumping station has a present pumping capacity of 15 mgd(US) to the plant and 20 mgd(US) to the well recharge system. Allowance has been made for expanding the plant supply to 45 mgd (US) when required.

Chemical Addition and Mixing

The raw water is pre-chlorinated and liquid alum is injected immediately upstream of a Parshall flume which is used for both mixing and flow measurement. Provision has also been made for the addition of lime and activated carbon at this point if required.

The alum dosage varies from 1.0 to 15.0 ppm depending on raw water quality.

Flocculation and Settling

After the addition of alum, flocculation time of approximately 10 minutes is provided in the distributon channels leading to the sedimentation basins.

Two sedimentation basins with a total volume of approximately 800,000 gallons (US) provide a retention time of 1¼ hours at the design flow of 15 mgd(US). At the present average flow of 8.8 mgd(US) a retention period of approximately 2¼ hours is provided.

No records are kept of water quality leaving the sedimentation basins but the operators report that at low turbidities very little sedimentation takes place. The normal maximum turbidity of the raw water is approximately 12 ppm and at this level almost all of the particulate matter is applied to the filters. As the raw water turbidity increases the sedimentation basins become more effective in removing particulate matter. The operators estimate that the maximum particulate matter loading applied to the filters under the most unfavourable conditions does not exceed 30 - 50 ppm.

Filtration

Four high-rate filtration units are provided, each unit having a surface area of 528 square feet. The filters have a standard underdrain and gravel support layer. Overlaying the gravel is an 8 inch "Muscatine" sand layer with an effective grain size of 0.4 mm. On top of the sand is a 22-inch anthracite layer with an effective grain size of 1.0 mm.

The filters are designed for a flow rate of 5 gpm(US)/ft^2, but are operated at rates varying from 2½ to 10 gpm(US)/ft^2.

Filter runs vary with raw water quality and filtration rate. With an applied turbidity of 12 JU (raw water) a filter run of approximately 15 hours is obtained with a head loss of 8 feet.

The finished water turbidity is maintained at 0.02 JU.

Occasional algae growths are experienced but these are moderate. Activated carbon is then used in dosages of approximately 1 ppm and it is reported that both algae and carbon are removed by settling and filtration. No problems of breakthrough are reported.

Backwash

The filters are backwashed when required by either head loss or breakthrough, although head loss is the usual limiting factor.

Backwash water is applied at a rate of 15 gpm/ft^2 and usually requires approximately 100,000 gallons per filter unit.

Based on a 15 hour filter run at 7 gpm/ft^2 the backwash water is equivalent to 3% of production.

Coagulant Aid

An organic polyelectrolyte is added to the water prior to filtration. Dosages vary with water quality and are generally higher in cold temperatures. Amounts varying from 0.005 to 0.1 ppm are used.

Control

The major control feature of the Columbia Water Treatment Plant is a pilot filter used to determine the filterability of the raw water after addition of lime. Sampling time is approximately 10 minutes and thus a result is obtained well in advance of any water thus sampled reaching the main filters. Turbidity of the pilot filter is monitored and coagulant feed adjustments are made manually when the effluent turbidity exceeds 0.02 JU. If the amount of alum adjustment is not obvious, a jar test is performed.

3.4.3 Water Quality

Raw Water

a)	Bacterial	- coliform	10-200/100 ml
b)	Chemical	- hardness	60 - 80 ppm
		- alkalinity	70 - 80 ppm
		- iron	0.2 - 0.4 ppm
		- chlorides	10 - 15 ppm
		- pH	8.1 - 8.5
c)	Biological	- algae	infrequent and light
d)	Turbidity	-	1 - 20 JU normal 200 JU max.

Finished Water

a)	Bacterial	- coliform	0
b)	Chemical	- hardness	60 - 80 ppm
		- alkalinity	55 - 65 ppm
		- iron	0.07 ppm
		- chlorides	2.6 ppm
		- pH	7.3 - 7.9
c)	Biological	- algae	0
d)	Turbidity	-	0.02 JU

3.4.4 Operation

A superintendent is responsible for both the water and sewage treatment plants. The water treatment plant staff, under the superintendent, consists of an operations foreman and a chief plant operator, both of whom divide their time between the water and sewage treatment plants. The staff of the plants also alternates between operation of the water and sewage treatment plants but during any week there are four operators

assigned, on a three shift basis, to the water plant. A maintenance crew consisting of a relief operator, operator-craftsman, pump attendant, serviceman and labourer are also available as required.

Operators are required to have the equivalent of a high school education and some experience in a field related to the operation of a water or sewage treatment plant.

3.4.5 Economics

The cost of constructing the water treatment plant (1963) was \$835,000 (US) with the intake structure costing an additional \$425,000.

Operating costs for 1965 were approximately \$75.00 per million gallons (US).

3.4.6 Summary

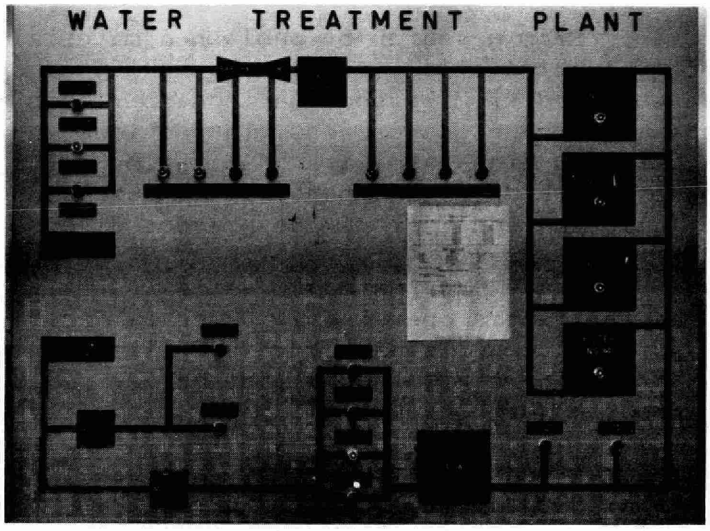
The Columbia Water Treatment Plant, constructed in 1963 has been designed to use a high-rate water filtration process. Present plant capacity is 15 mgd(US) although future expansion to 45 mgd is proposed. All piping and hydraulic design has been based on a design capacity of 45 mgd.

The plant facilities include, in addition to a raw water pumping station, a Parshall flume which acts as both a flow measuring device and a chemical mixing chamber, two sedimentation basins providing 1¼ hours retention at a flow rate of 15 mgd (US), and four filters with a total surface area of 2,100 square feet and rated at a design capacity of 7 gpm(US)/ft^2 flow rate.

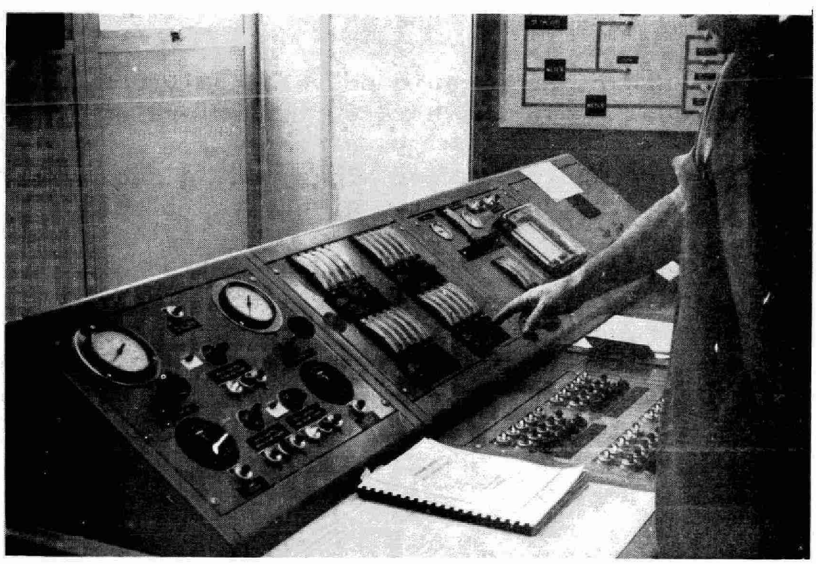
The raw water quality is very good with normal turbidities of less than 20 JU and infrequent, light density, algae growths.

The quality of finished water is good, having turbidity not exceeding 0.02 JU.

Columbia Water Treatment Plant



Schematic Flow Diagram



Filter Control Panel

4.0 CONCLUSIONS

From a search of published material, a theoretical evaluation of the process, a review of operating data obtained from persons having experience in operating plants utilizing the process, inspections and observations of operating high-rate water filtration units, and discussions with operating personnel at such installations, the following conclusions are presented:

a) If adequate pretreatment facilities are provided, dual-media filters operated at rates in excess of 2 gallons per minute per square foot of filter surface area will produce a water of equal, or better quality than that produced by conventional rapid-sand filters.

b) Pretreatment facilities must be such that water containing turbidity of not greater than 35 Jackson units is applied to the filters.

c) Accurate monitoring of water quality is of great importance in any water treatment facility. Recording turbidimeters should be installed to monitor raw water, sedimentation basin effluent and filter effluent quality. Pilot filters, when used in conjunction with jar tests, may be of value in determining coagulant dosages.

d) The use of an organic polyelectrolyte is necessary if dual-media, high-rate filters are employed.

e) Low concentrations of algae can be economically removed by dual-media, high-rate filters.

f) Unusual raw water quality (e.g. low temperature, colour, etc.) will cause treatment difficulties in a high-rate filtration process to the same degree as in conventional facilities. There was no indication that such difficulties would be more severe in a high-rate process.

5.0 RECOMMENDATIONS

The following recommendations are presented with respect to the use of dual-media, high-rate filters.

a) Dual-media high-rate water filters may be rated at 5 gallons per minute per square foot of surface area. All piping, valves, etc. should have a hydraulic capacity equivalent to a filter flow rate of 8 gpm/ft^2.

b) Pretreatment in the form of flocculation and sedimentation basins should be installed so that a settling basin retention period of not less than 2 hours is provided at flows equivalent to a filter flow rate of 5 gpm/ft^2.

c) Provision should be made so that water containing not more than 35 Jackson Units of turbidity is applied to the filters.

d) Recording turbidity meters should be installed to monitor raw water, sedimentation basin effluent and filter effluent quality. The provision of a pilot filter, to be used in conjunction with jar testing, is desirable.

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